Micro–Computed Tomography Study of the Internal Anatomy of Mesial Root Canals of Mandibular Molars

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Abstract

Introduction: The aim of this study was to determine the mesiodistal and buccolingual diameter, apical volume, and the presence of isthmuses at the apical level of mesial root canals of mandibular molars. **Methods:** Sixty extracted first and second mandibular molars were scanned by using a SkyScan 1076 micro–computed tomography system with a voxel size of 18 μm. The apical thirds of the samples were reconstructed to allow a perpendicular section of the apical third by using the multiplanar reconstruction tool of the OsiriX software. The mesiodistal and the buccolingual distances of root canals were measured between the 1- to 4-mm levels. The type of root canal isthmuses present at these levels was classified by using modified criteria of Hsu and Kim. The volume of the root canal anatomy between the 1- to 3-mm apical levels was obtained by using the CTAN-CTVOL software. **Results:** The medians of the mesiodistal diameter at the 1-, 2-, 3-, and 4-mm levels in the mesiobuccal and mesiolingual canals were 0.22 and 0.23 mm, 0.27 and 0.27 mm, 0.30 and 0.30 mm, and 0.36 and 0.35 mm, respectively. The buccolingual lengths at the 1-, 2-, 3-, and 4-mm levels were 0.37–0.35 mm, 0.55–0.41 mm, 0.54–0.49 mm, and 0.54 and 0.60 mm, respectively. The presence of isthmuses was more prevalent at the 3- to 4-mm level. However, 27 cases presented complete or incomplete isthmuses at the 1-mm apical level. The mean of the volume of the apical third was 0.83 mm^3, with a minimum value of 0.02 and a maximum value of 2.4 mm^3. **Conclusions:** Mesial root canals of mandibular molars do not present a consistent pattern. A high variability of apical diameters exists. The presence of isthmuses at the apical third was not uncommon even at the 1-mm apical level. *(J Endod 2011;■:1–5)*

Key Words

Dental anatomy, mandibular molars, micro–computed tomography

Knowledge of the dimensional variations of complex root canal systems such as those in mesial roots of mandibular molars is indispensable to support clinical decisions during endodontic procedures. Anatomical knowledge includes distinguishing the presence of isthmuses during surgical or nonsurgical treatment (1, 2) and an appropriate determination of the apical anatomical diameter (3). These anatomical variables cannot be determined in the typical radiographic exam taken before treatment and can compromise the cleaning and shaping procedure of endodontic treatment, which decreases the success rate because of the infectious characteristics of apical periodontitis.

Previous studies have described the apical diameter of internal anatomy of several groups of teeth (3–5). Adequate apical diameter determination is only reliable if the cross sections are taken perpendicular to the long axis of the root canal (6). However, the determination of the apical diameter in curved root canals such as mesial root canals of mandibular molars can be difficult with this method. At least 3 limitations to performing adequate cross sections are identified. (1) The root canal foramen is not always present at the anatomical root apex (7, 8); consequently, the root canal curvature in the last apical millimeter does not always resemble the trajectory of the external anatomy. (2) Mandibular molars present multiplanar curvatures in 100% of cases in both mesiodistal and buccolingual directions (9). (3) The main apical foramen of the buccal and lingual canals can be present at different levels, which makes it difficult to find an exact section at the same level for both canals. In addition, the presence of isthmuses is not uncommon (10), and these data have not been reported in previous studies that addressed the canal diameter determination (4). The concept of enlarging the root canal by using 3 larger files to eliminate the infected dentin at the total circumference might not be applicable when an isthmus is present. Consequently, it is not clear what percentage of root canal walls of mandibular molars can be appropriately enlarged by mechanical means, especially at the apical third.

Micro–computed tomography (micro-CT) is a nondestructive technology that is useful to evaluate the apical diameter of mandibular molars in which 2 canals are present, because the sections can be nondestructively reoriented in several ways to gain a perpendicular section for each canal in both planes. In addition, the apical volume of the root canals including fins and isthmuses can be properly quantified by using dedicated software (11), and the results can be compared with the volume of endodontic instruments (12).

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Apical volume and percentage of untreated surfaces after rotary instrumentation are variables that have been extensively studied by using micro-CT technology in maxillary molars (13). However, the apical volume in mandibular molars before instrumentation procedures has not been extensively studied except for 2 previous studies that reported the total volume of this root canal system (14, 15).

Accuracy of micro-CT linear and volumetric measurements on extracted teeth has been previously reported (16–18). Therefore, a more reliable determination of the apical diameter could be expected in comparison to previous studies that used horizontal cross sections. To date, there is no report addressing the apical diameter of mandibular molars by using micro-CT. The aim of this study was to determine the mesiodistal and buccolingual diameter, apical volume, and the presence of isthmuses at the apical level of mesial root canals of mandibular molars.

Materials and Methods

Sixty extracted first and second mandibular molars with curvatures between 20° and 35° and 19- to 21-mm length were selected (19). The teeth were extracted for extensive caries or coronal fractures, and ethical requirements for the use of extracted teeth were followed (CEP 131-2010). After extraction, the teeth were immediately stored in 10% formalin solution.

The samples were scanned by using a micro-CT system (Skyscan 1076, Kontich, Belgium) with a voxel size of 18 μm. The complete "stack" was exported as TIFF files and then imported to the OsiriX software (http://www.osirix-viewer.com). This software has been used previously for measurements of micro-CT data of hominin fossil teeth (20). Appropriate calibration of the voxel size was performed to allow posterior measurements. Then the apical thirds of the samples were reconstructed to allow a perpendicular section of each mesial root canal at the 1- to 4-mm apical third levels according to Weiger et al (6). For this purpose the multiplanar reconstruction tool of the OsiriX software was used. The mesiodistal and buccolingual distances of the mesial canals were calculated by using the measurement tool of the OsiriX software, and the results were expressed in micrometers. Buccolingual distances were measured when an isthmus was not present or when an incomplete isthmus did not cross the middle line of the root. To confirm the accuracy of the measurements, an object with a known geometry (ProTaper F2 instrument; Dentsply-Maillefer, Baillagues, Switzerland) was scanned by using the described protocol. The instrument was sectioned at the 21-mm level by using an IsoMet (Buehler, Lake Bluff, IL) saw machine, and the expected diameter of the instrument (1.2 mm) was verified by using a stereomicroscope (Stemi 2000C; Carl Zeiss, Jena, Germany) and the Axiovision software (Carl Zeiss) at 40×; the measurement was compared with the micro-CT value found by using the OsiriX software.

The type of root canal isthmus present at the 1- to 4-mm levels was classified by 2 independent evaluators by using the criteria of Hsu and Kim (21). In Type I, there are 2 or 3 canals with no notable communication. In Type II, there are 2 canals with a connection between the 2

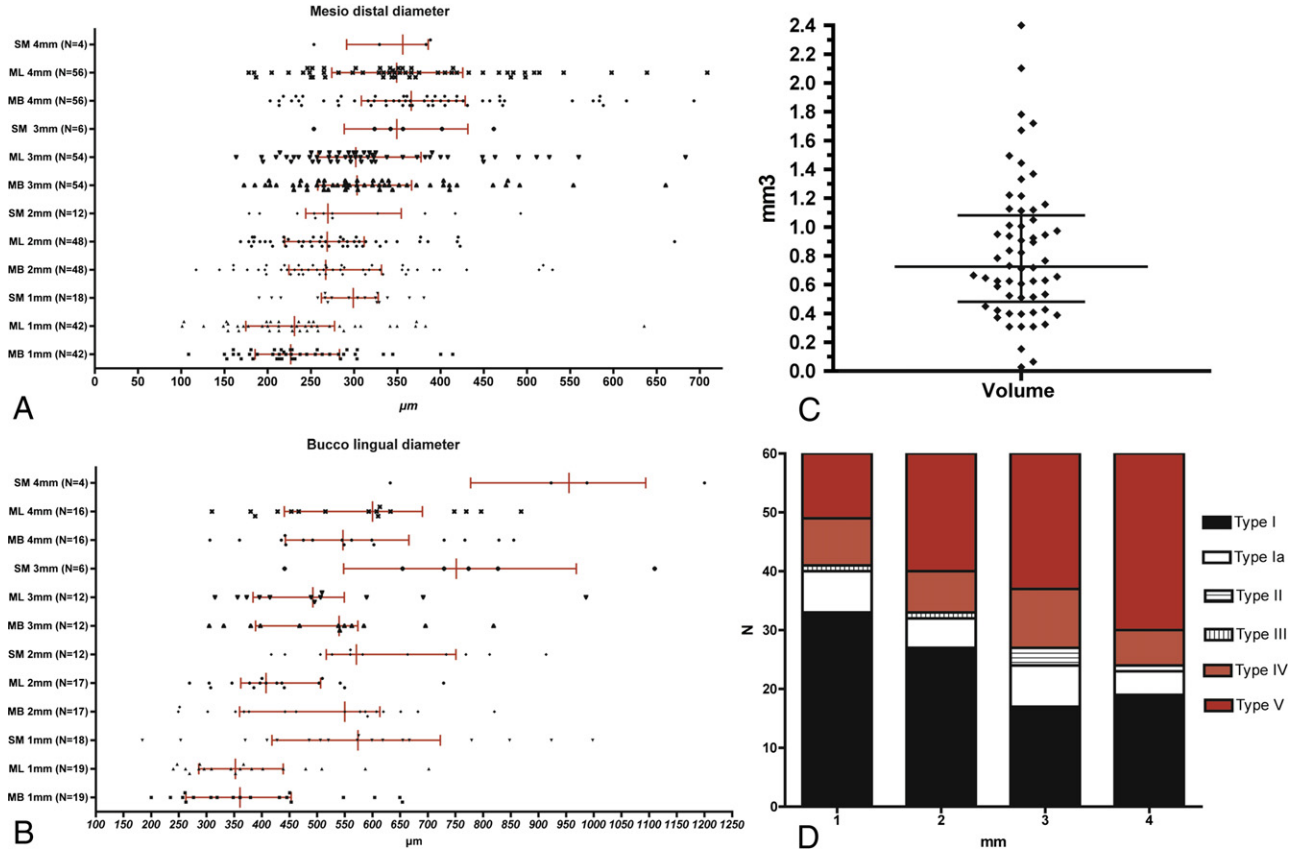

Figure 1. (*A*) Mesiodistal diameter distribution of values found at 1- to 4-mm apical levels. (*B*) Buccolingual diameter distribution of values found at 1- to 4-mm apical levels. The median and 25th–75th percentile of canal diameters are also shown. (*C*) Distribution of apical volumes found between the 1- and 3-mm levels in 60 samples. Values are expressed in mm^3. The median and 25th–75th percentile are also shown. (*D*) Distribution of isthmuses found at 1- to 4-mm apical levels in the categories studied. MB, mesiobuccal; ML, mesiolingual; SM, single mesial canal.

main canals. Type III differs from Type II because of the presence of 3 canals instead of 2 canals. In Type IV, canals extend to the isthmus area. Type V is defined as a true connection or corridor throughout the section. Incomplete isthmuses were classified as Type Ia. The apical volume between the 1- to 3-mm apical levels was determined by using the CTAN-CTVOL software, and the data were expressed in mm^3. Evaluations were made using descriptive statistics. Isthmus data were analyzed by the χ^2 test at a confidence level of $P < .05$.

Results

No differences were found for the stereomicroscope and micro-CT measurements of the evaluated endodontic instrument.

The presence of complete (Types II–V) and incomplete isthmuses (Ia) was a common finding at all the evaluated levels in 20 and 7 cases at the 1-mm level, 28 and 5 cases at the 2-mm level, 36 and 7 cases at the 3-mm level, and 37 and 4 cases at the 4-mm level, respectively, but the presence was statistically significant at the 3- and 4-mm levels in comparison to the 1-mm level (Fig. 1) ($P < .05$). For the buccolingual diameter determination, 3 incomplete isthmuses were found across the middle line of the mesial root at the 1-mm level, 3 at the 2-mm level, 6 at the 3-mm level, and 3 at the 4-mm level. These cases and types II–V isthmuses were excluded for the determination of the buccolingual diameter. Buccolingual diameter determination was possible in 37, 29, 18, and 20 cases at the 1-, 2-, 3-, and 4-mm levels, respectively. The medians, 25th–75th percentiles, and distribution of the values corresponding to the mesiodistal and buccolingual diameters are presented in Figure 1.

The median of apical volume was 0.72 mm^3, with a range of 0.03–2.41mm^3. The 25th–75th percentile was 0.48–1.08 mm^3, and the mean was 0.83 mm^3. Representative pictures of the internal anatomy of representative samples are shown in Figure 2.

Discussion

The study of the dimensions of the internal anatomy of teeth has been a challenge since the studies of Kuttler (22) and Kerekes and Tronstad (4). Although conventional radiographs used during clinical procedures can show important details such as the number of root canals, the severity of the root canal curvature, or the presence of calcifications, periapical x-rays are bidimensional images and do not provide enough details of the internal anatomy. For this reason anatomical studies are necessary to guide clinicians to achieve better cleaning of the root canals.

Previous studies (1, 10) and a recent systematic review (23) showed a high incidence of isthmuses in mandibular molars between the 2-mm and 4-mm levels. Those data are in agreement with the results of this study. However, an important point not fully addressed by previous studies addressing the apical diameter determination is that when a complete or incomplete isthmus is present, it is impossible to determine an exact buccolingual diameter. The aim of manual or rotary instrumentation is to enlarge the apical third for an appropriate irrigation to ensure the placement of medicaments and finally to facilitate filling procedures (24). It was found that in 23 cases the apical diameter could not be determined at the 1-mm apical level because of the presence of complete or incomplete isthmuses. Previous studies have shown that buccal and lingual areas of flattened root canals with or without isthmus cannot be completely reached by rotary instruments or filled appropriately (2, 25–27). Histologic and micro-CT studies have also found it difficult to

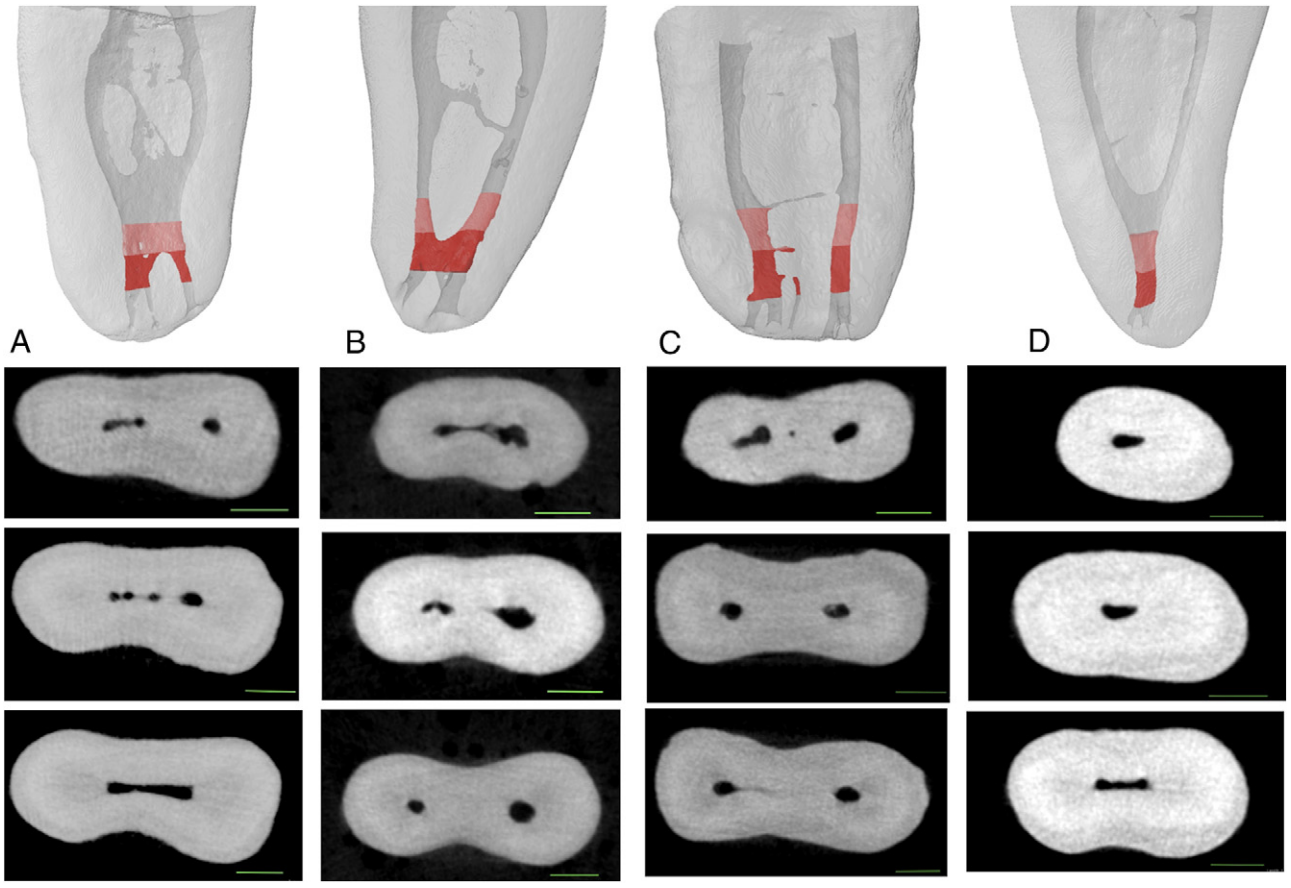

Figure 2. Tridimensional reconstructions and micro-CT sections of the studied samples at the 1- to 3-mm levels (bar represents 1 mm). The volume of interest studied between 1- to 2-mm and 2- to 3-mm levels is represented by different colors (*A–D*). A great variability of the internal root canal anatomy is observed.

instrument fully the root canal walls of maxillary molars after the use of rotary instruments (13, 28, 29). The large diameter found in the root canals at the 2- to 4-mm levels emphasizes that complete instrumentation of oval canals would lead to weakening of the roots, with or without rotary preparation techniques. The results of previous studies that addressed the cleaning of root canal isthmuses in mandibular molars lead us to the deduction that apical cleaning is also a function of the dissolution properties of sodium hypochlorite (30–32).

An important topic is advancing age of the patient at the moment of the extraction. By using micro-CT data, Gu et al (33) found that the isthmuses were more constricted mesiodistally with age (>60 years). Also, the incidence of isthmuses was lower in the patients older than 60 years when it was compared with molar teeth of a group of 20- to 39-year-old patients. The limitation of unknown age of the sample used in this study might affect the clinical extrapolation of the data. On the other hand, a previous study (5) failed to show a correlation between the apical diameter of maxillary molars and age. Clinical research has shown that isthmuses in mandibular molars are highly associated with failure of endodontic treatment (2, 34, 35). The presence of bacterial biofilms at the apical third after endodontic treatment has also been confirmed in these anatomical irregularities (35, 36). The apical diameter results found in this study are in agreement with previous reports that used fewer numbers of samples (3, 4).

The apical volume of the root canal system between 1- to 3-mm levels that was measured in this study can give an approximate idea of the amount of dentin that can be removed by the instrumentation process. Considering that shaping procedures are usually performed 1 mm beyond the apical foramen (27), the volume of an instrument between D0 and D2 can be calculated by using previous reported values (12). By using micro-CT data, Grande et al (12) measured the volume of nickel-titanium rotary instruments (Mtwo; VDW, Munich, Germany. ProTaper; Dentsply, Ballaigues, Switzerland). The values found between D0 and D2 for 2 instruments (1 for each mesial canal) were calculated as the following: 25.06 (0.12 mm^3), 25.08 (0.19 mm^3), 30.09 (0.26 mm^3), 35.04 (0.23 mm^3), and 40.04 (0.29 mm^3). Considering the continuous rotation of rotary instruments, the data can also be calculated by using the formula of the truncated cone, when knowing the radius of the base, the radius of the top, and the height $V = (\pi \times h \div 3) \times (R^2 + r^2 + R \times r)$. With this formula, theoretically the volume between D0 and D2 of 2 instruments was calculated as 25.06 (0.30 mm^3), 25.08 (0.34 mm^3), 35.04 (0.48 mm^3), and 40.04 (0.60 mm^3). Our results showed a mean of the apical volume of 0.83 mm^3 and a median of 0.72 mm^3. Hypothetically, this discrepancy between the apical volume of instruments used for cleaning and shaping process and preoperative apical root canal volume of the studied samples shows that mesial root canals of mandibular molars can be a challenge to obtain proper root canal cleaning (27).

It can be concluded that mesial root canals of mandibular molars do not follow a consistent pattern. There was a high variability of apical diameters, but they were generally large, especially in the buccolingual dimension. The presence of isthmuses at the apical third was not uncommon even at the 1-mm apical level.

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The authors deny any conflicts of interest related to this study.

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